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DESIGN OF A GAS JET TARGET OPERATING AT AMBIENT TEMPERATURE IN THE MAIN RING

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Summary

A design of a gas jet target operating at room temperature for use in the Main Ring is presented. This target yields a source size of 5mm and will operate in the range of target thickness from 0.2×10^{-8} to 20×10^{-8} g/cm² (H_2 gas). The design takes advantage of the small angular divergence of the jet produced by the 0.004" Los Alamos de Laval nozzle to "capture" 85% of the jet gas in a 1000 liter buffer volume which is separate from the main vacuum chamber. By virtue of its economy of operation, greater flexibility, and good reliability, this target should significantly enhance the research capability of the Internal Target Area.

Introduction

The feasibility of a practical gas jet target that would operate at ambient temperature and could be used at C0 has been studied in a previous report.[1] The advantages (and disadvantages) of such a target over the presently used liquid He target have been treated extensively there. In this report we present a specific design for such a target using the 0.004" throat Los Alamos type de Laval nozzle. The design is based primarily on the experimental information obtained in the feasibility study and described in the previous report.

Basic Design Considerations

One of the constraints imposed on the target is that it make no restriction on the vertical aperature for the proton beam of the Main Ring, i.e., ±2.54cm vertical clearance around the beam. In the above study[1] with the .004" nozzle it was shown that at a beam-to-nozzle distance of 2.54cm the target thickness, $\rho\ell$ (jet density x FWHM of jet), was related to pressure before the nozzle, P_o, by

$$\rho\ell = \frac{P_0(\text{atm})}{23.4} \; 10^{-7}\text{g/cm}^2 \tag{1}$$

and the gas flow, Q, through the nozzle was given by

$$\begin{aligned} Q &= 6.11\ P_o(\text{atm})\ \frac{\text{cm}^3\text{-atm}}{\text{sec}} \\ &= 4.65\ P_o(\text{atm})\ \frac{\text{liter-Torr}}{\text{sec}} \end{aligned} \tag{2}$$

Hence to achieve $\rho\ell \sim 1 \times 10^{-7}$g/cm^2 implies Q ~100 liter-Torr/sec. To run continuously at this flow and maintain a vacuum of 10^{-3}Torr would then take a pumping speed of ~1 x 10^5 liters/sec which is hardly consistent with fitting easily into the CO environment. One must resort to a pulsed jet; for a 10% duty cycle one is then dealing with ~15cm^3 of NTP gas per sec, or at 3 pulses/sec, 5cm^3 of gas per pulse.

It is clearly desirable to confine the gas to a region of the Main Ring vacuum chamber as small as possible in the vicinity of the jet. The most effective solution for high pumping speeds at ~10^{-3}Torr is the oil diffusion pump (ODP). Given this type of pump, it follows that a vacuum system of volume ~1m^3 is required. Most ODP's reach maximum throughout (Q) at inlet pressures of ~3 x 10^{-3} Torr, and for much higher pressures become unstable. In order to smooth out the gas load on the pump (i.e. keep $\underline{P}_{max} \leq 3 \times 10^{-3}$ Torr) we need a volume (upper limit)

$$V = \frac{5\ \text{atm-cm}^3}{3 \times 10^{-3}\ \text{Torr}} \times 760\ \frac{\text{Torr}}{\text{atm}} = 1.3\text{m}^3 \tag{3}$$

In designing the system, the directed nature of the gas in the jet can also be used to advantage in two areas: (1) to increase ρ_{JET}/ρ_{BKG}, the ratio of density of gas in the jet to density of gas along the beam upstream and downstream of the jet, (2) to "trap" the jet gas into a chamber which is isolated from the Main Ring vacuum chamber; this is useful when operating with a contaminating gas such as He. In the feasibility study it was shown that 86% of the gas from the jet will pass through a 3.8cm diameter hole placed 5.1cm from the nozzle tip.

We arrive then at the following scheme

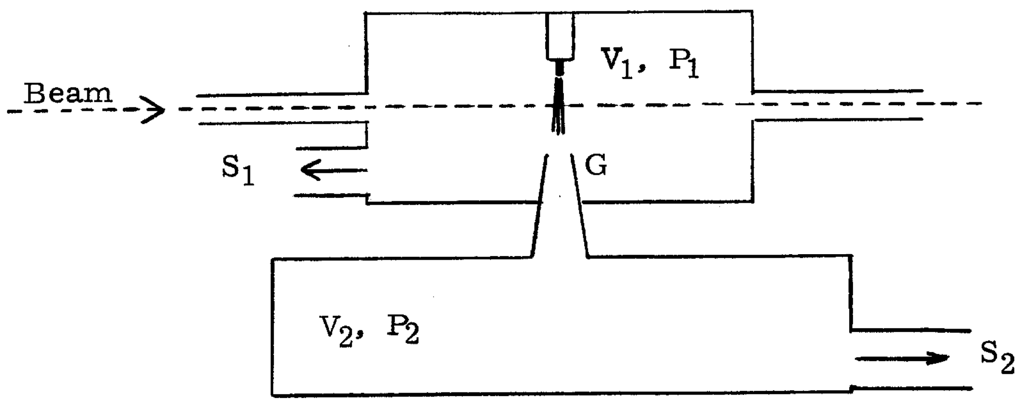


Fig. 1

Most of the jet gas (~85%) goes into V_2, which we have seen must be ~$1m^3$. The pumping speed on V_2, S_2, then determines how quickly the system will recover to allow a subsequent pulse and also how much of the gas leaks back into V_1. The conductance of the receiver cone, G, for back flow can be as low as ~200ℓ/sec (H_2 gas); hence an S_2 ~10^4ℓ/sec will give a recovery time of ~½ sec and a back flow of ≤2%. V_1 and S_1 will determine $\langle \rho_{JET}/\rho_{BKG} \rangle$; to limit P_{max} in V_1 one would need $V_1 \geq \frac{15}{85} \times V_2 = V_2/5.7$.

Configuration of System

Figure 2 shows both a top view and a side view of a vacuum system compatible with the space available at CO. The volume V_1 (see Figure 1) is a rectangular box 42" x 18" x 15" (L x W x H) with volume 160 liters. The volume V_2 is basically a 30" diameter tube 6' long of volume ~1000 liters. V_1 and V_2 are connected by a conical receiver which starts 5.1cm below the nozzle (2.5cm below the beam); it is 25cm long with a 3.8cm diameter top hole and a 7.6cm bottom hole. This receiver is estimated to have a conductance of ~200 liters/sec for H_2 gas at 295°K.

There are four identical ODP's on the system, two which pump V_1 and have cooled baffles (either H_2O or liquid N_2), and two which pump V_2 and are unbaffled. The pumps are taken to have H_2 speeds of 4000 liters/sec (2000 liter/sec with baffle) and throughputs of ~5 Torr-liters/sec. The top flange of the pump is taken as 16" OD and overall height ≤22".

Jet Density, Duty Cycle, and Background Pressure

The basic parameters of the systems are:

a) $V_1 = 160\ell$, $S_1 = 4000\ell/\text{sec}$, $\frac{V_1}{S_1} = 40\text{msec}$.

b) $V_2 = 1000\ell$, $S_2 = 8000\ell/\text{sec}$, $\frac{V_2}{S_2} = 125$ msec.

c) $F_{CONE} = 200\ell/\text{sec}$, 85% of jet into V_2.

d) $\rho\ell$ and Q vs. P_o for the .004" nozzle are given in eqs. (1) and (2).

To illustrate jet target performance, assume we inject a constant 6.75cm^3 of NTP H_2 gas with each pulse, i.e., we vary $\rho\ell$ by varying P_o and t_o, the length of each pulse. Equation (2) then relates P_o and t_o as follows

$$P_o = \frac{6.75}{6.11}\ \frac{1}{t_o}\ \text{atm} = \frac{1.10}{t_o}\ \text{atm}. \tag{4}$$

and $\rho\ell$ for a given (P_o, t_o) follows from eq. (1). Since the pulse risetime is ~7msec, we take 20msec as the minimum pulse width. In Figures 4-5 we plot vs. $\rho\ell$

(1) t_o = pulse length

(2) cycle time

(3) P_{1max}, P_{2max} (see Figure 1) peak pressure

(4) $\langle P \rangle$ = average pressuring during pulse

(5) $\langle \rho_{JET}/\rho_{BKG} \rangle$, averaged over the pulse.

We determine duty cycle by somewhat arbitrarily allowing 300msec from end of pulse to start of next pulse. Since the limiting time constant is 125msec, this will give a 10% rise in P_{2max} after a series of pulses, but a negligible rise in P_{1max} since $F_c/S_1 = 1/20$.

We observe from Figure 3:

(a) a $\rho\ell)_{max}$ of 2.3×10^{-7}g/cm² at a 20msec pulse length and a repetition rate of 3.1 pulses/sec.

(b) continuous operation for $\rho\ell \leq 1.3 \times 10^{-8}$g/cm²

(c) $\rho\ell = 1.0 \times 10^{-7}$g/cm² at a 45msec pulse (2.9 pulses/sec)

(d) $\langle \rho_{JET}/\rho_{BKG} \rangle \geq 465$, (note for a given $\rho\ell$ one can improve $\langle \rho_{JET}/\rho_{BKG} \rangle$ by decreasing t_o)

(e) we have calculated P_1 and P_2 as if they were not connected by F_c, from Figure 5 we note that they are sufficiently close to justify this approximation.

The t_o vs $\rho\ell$ we have plotted in Figure 3 is the maximum t_o for that $\rho\ell$, one can always run with a smaller t_o, which will reduce the duty cycle but improve $\langle \rho_{JET}/\rho_{BKG} \rangle$. In the illustration given here, we have purposely pushed the pumps to their limits (in the case of ODP3, 4, perhaps beyond for $\rho\ell > .5 \times 10^{-7}$g/cm²). If the pumps will not take this load, one will adjust by reducing P_o for a given t_o; in any case one would expect not more than a 25% reduction in P_o (hence in $\rho\ell$).

Diffusion Pumps Available

There are two commercially made ODP's which will probably meet the specifications set in the section above. Their advertised properties are:

(a) Veeco 10" Pump
S(air) = 3000 liters/sec.
Pump Height = 20.5"
Heater Power = 1.8kW

(b) Varian VHS-250 (from M2000 Stack)
S(air) = 3700 liters/sec
S(He, H_2) = 4400 liters/sec

Pump Height = 22"

Heater Power = 2.2kW

Q_{max}(air) = 3.5 Torr-liters/sec.

The VHS-250 is somewhat higher capacity and probably does less backstreaming when run unbaffled.

Other Considerations

The system shown in Figure 2 has gate valves only where the beam enters and leaves V_1. Without much additional effort, one could also insert a gate valve at G where V_1 and V_2 join; a 2.5" diameter opening would be sufficient.

Oil backstreaming from ODP3 and ODP4 into V_1 should not be a problem since there are at least four room temperature surfaces which could capture the oil molecule before it can enter V_1. Commercially available water-cooled baffles for ODP1 and ODP2 are advertised to reduce the backstreaming level below 1×10^{-9} g/cm^2-sec. In addition it might be advantageous to use SANTOVAC oil in DP1 and DP2, which is not supposed to creep as much as silicone oils. If this level of backstreaming is objectionable, there is adequate vertical space to replace the H_2O cooled baffle with a liquid N_2 baffle.

The receiver cone below the nozzle can be made very low mass (e.g., 0.002" mylar) since there is little force on it.

Cost Estimate

A crude cost estimate is:

4x VHS-250 Pumps	6.6
4x 8 liter/sec Mechanical Pumps	4.0
2x H_2O Cooled Traps	1.7
(2x LN_2 Traps)	(4.0)
Vacuum Tank Materials and Fabrication	5.0
2x 5" Gate Valves	2.0
Solenoid Pulsing System	0.5
Total	$ 20 K

Summary and Conclusion

We have presented the essential design features of a gas jet target that operates at ambient temperature and fits easily into the C0 environment. With H_2 gas this target can achieve target thicknesses in the range $0.2\text{-}20 \times 10^{-8}$g/cm^2; at the high end it operates in pulsed mode ($t_o \gtrsim 20$msec with cycle rate ~3/sec) and at the low end ($\rho\ell \lesssim 1 \times 10^{-8}$) will operate continuously. The small angular divergence of the jet produced by the Los Alamos nozzle (~9°) allows one to obtain simultaneously: (1) a full ±2.5cm vertical aperture for the proton beam, (2) a small interaction region, 5mm, and (3) substantial densities with modest sized pumps. In addition the design utilizes the narrow divergence to "trap" ~85% of the gas from the jet into a separate volume that does not (almost) communicate with the proton beam pipe, a useful feature, especially when operating with "contaminating" gas such as He. It is expected that the target will readily operate with any gas[2] that is noncorrosive and does not react with diffusion pump oil.

We conclude that a target of this design would be a valuable addition to the C0 facility, it would significantly enhance the flexibility, productivity, and scope of the research program at the Internal Target Area. Savings due to simplified operations would quickly pay for the modest hardware investment (~20K$). What is probably more important however, is that it will permit the present staff to meet the growing demands presented by the sophisticated spectrometer systems now being set up in the new Spectrometer Room.

References

1. P. Mantsch and F. Turkot, "Feasibility Study of a Gas Jet Target Without Liquid Helium for Use in the Main Ring", Fermilab Report TM-582 (1975).
2. An example with He gas is discussed in Appendix I.

APPENDIX I

Performance With He Gas

We give an example of how this target system would work with He gas. Experiment 289 proposes to have a 25msec long pulse with target thickness

$$7 \times 10^{-8} \frac{G}{cm^3} \times 1.2cm$$

achieved by injecting $2.8cm^3$ of He gas (NTP).

From the formula in Reference 1 one gets the He quantities for the room temperature target as

$$\rho_{He} = 0.222 \quad P_o(atm)\ 10^{-7}\ /cm^3$$

$$Q_{He} = 4.60\ P_o \frac{cm^3 - atm}{sec} \tag{5}$$

$$\left(\rho_{JET}/\rho_{BKG}\right)_{He} = 1.67 \left(\rho_{JET}/\rho_{BKG}\right)_{H_2}$$

where one assumes the same profile and pumping speeds for H_2 and He to get the last relation. Hence to obtain the above $\rho\ell$ for $\ell = 0.5cm$ we need operate with.

$$P_o = \frac{.7 \times 10^{-7}}{0.222} \times \frac{1.2}{0.5} = 7.57 \text{ atm.}$$

$$Qt_o = 4.60 \times 7.57 \times .025 = .87cm^3\text{-atm.}$$

The peak pressure for a t_o = 25msec is obtained from Figure 3 by scaling by 0.87/6.75, giving

$$P_{1max} = 4.6 \times 10^{-4} \text{ Torr.}$$

The pressure transient in V_1 will have a FWHM of 40msec, hence

$$L \equiv \int_0^\infty P_1(t)dt \approx 4.6 \times 10^{-4} \times 0.04 = 0.18 \times 10^{-4} \text{ Torr sec} \tag{6}$$

The quantity of He gas that escapes toward the Main Ring vacuum system is proportional to L.

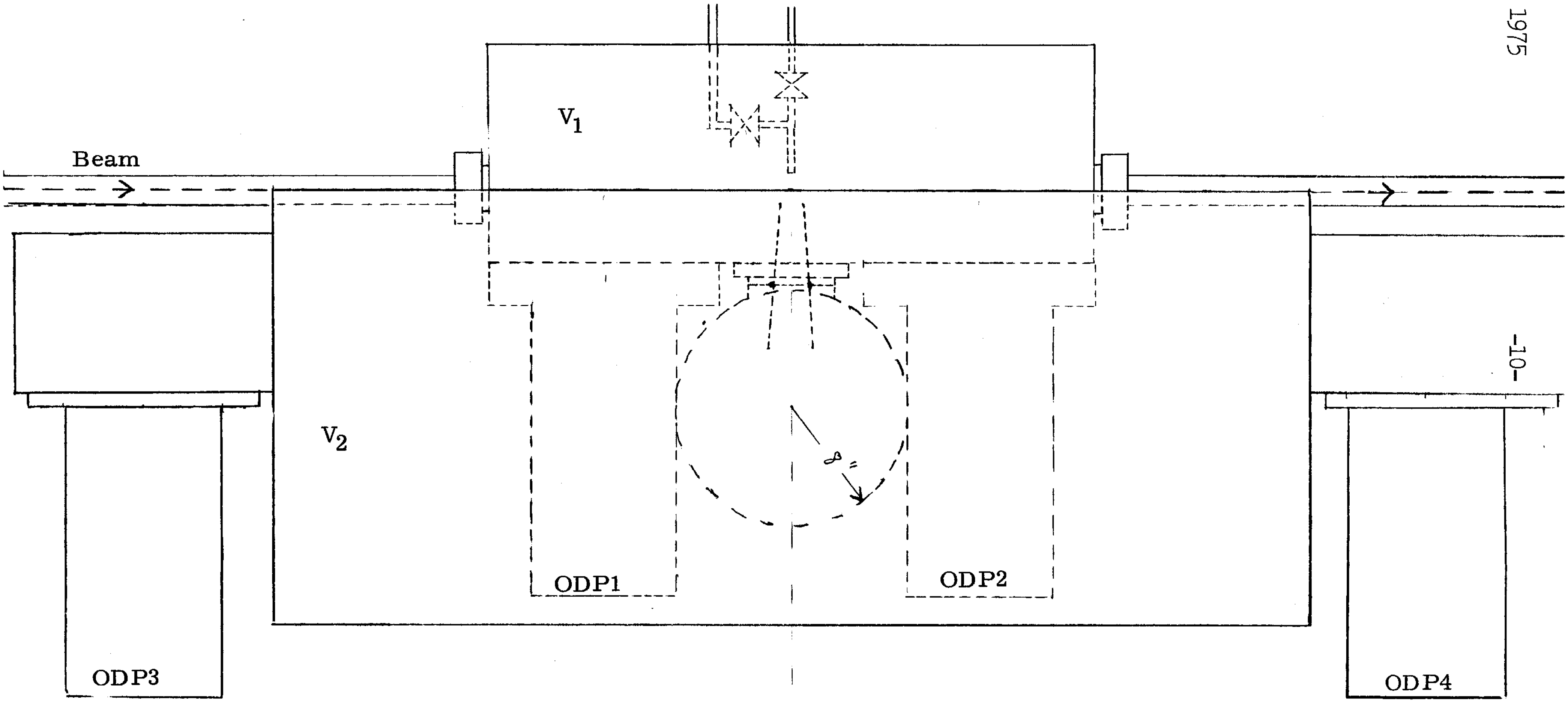
APPENDIX I, continued

Using the last of eq. (5) and Figure 4 we find

$$\left\langle \rho_{JET}/\rho_{BKG} \right\rangle = 3023.$$

With regard to recovery time the system is ready to pulse again after ~325msec. The peak pressures and throughputs are so far from the limits of the pumps, that one can be rather confident of achieving this performance.

Fig. 2A Sideview of Gas Jet Target Vacuum System



ODP1, 2, 3, 4	10" pumps
ODP3, 4	No baffle, 4000 liter/sec (H_2 gas)
ODP1, 2	Cooled baffle, 2000 liter/sec

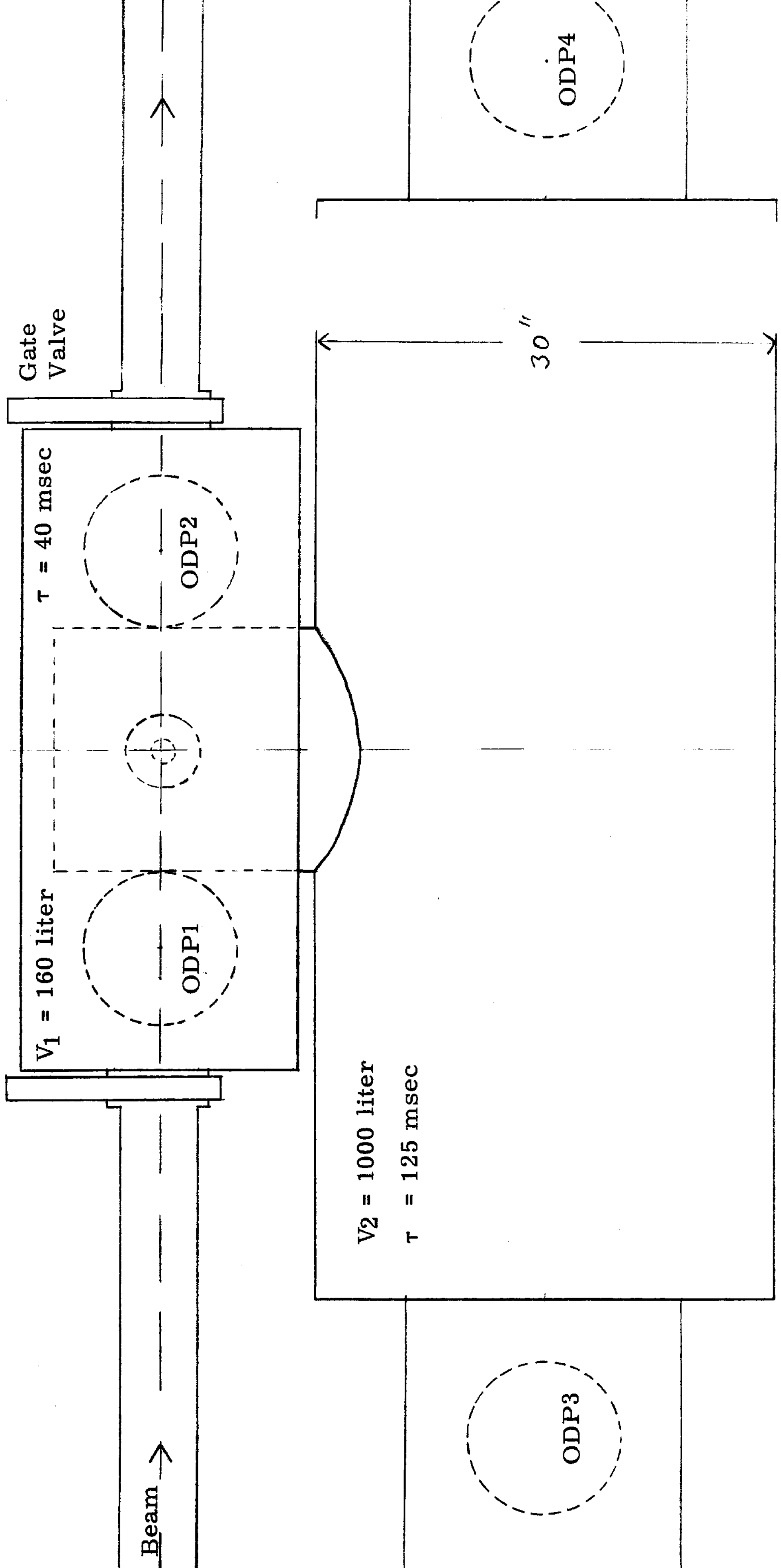


Fig. 2B Top View of Gas Jet Target Vacuum System

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Fig. 3

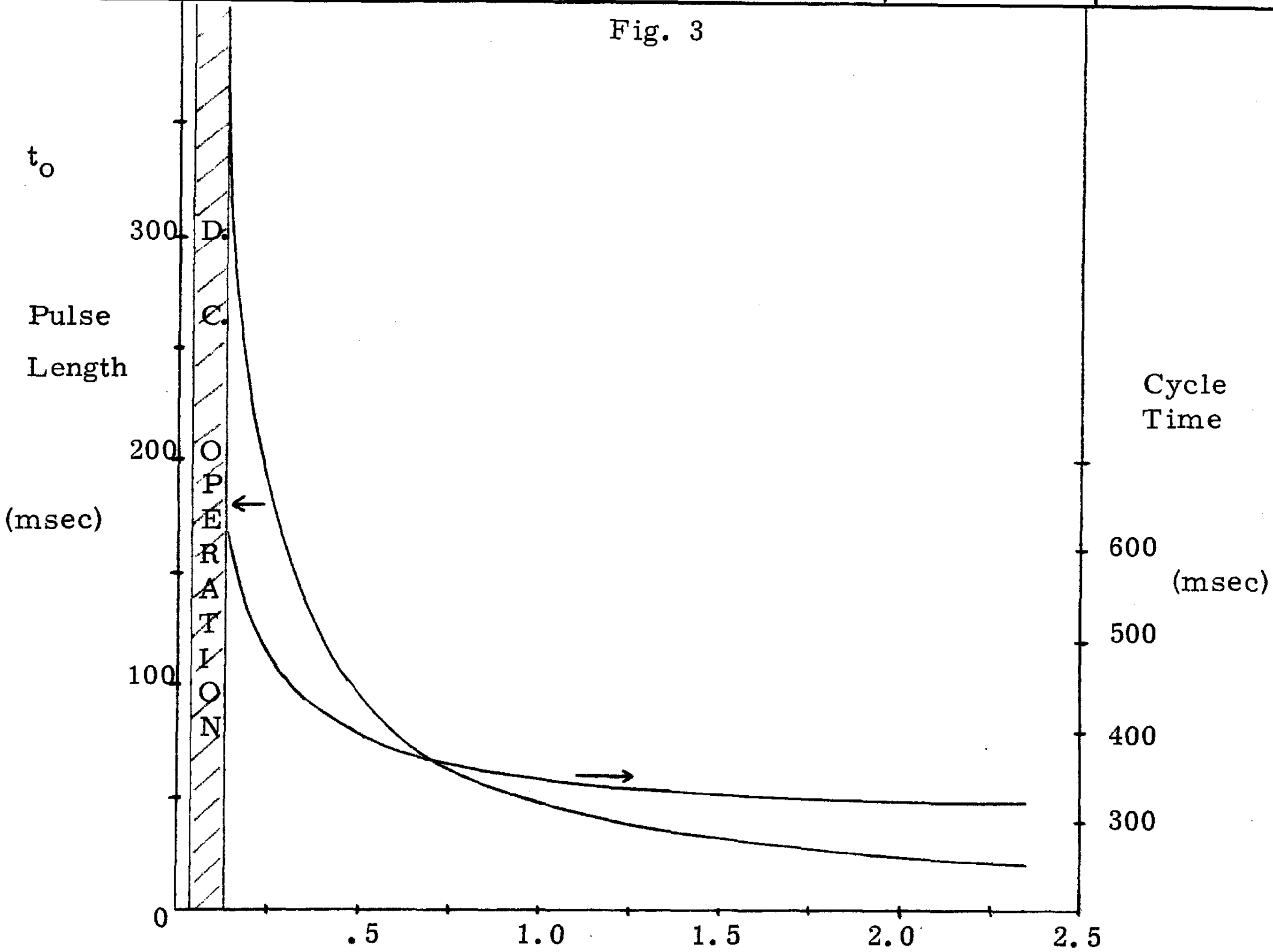

Fig. 4

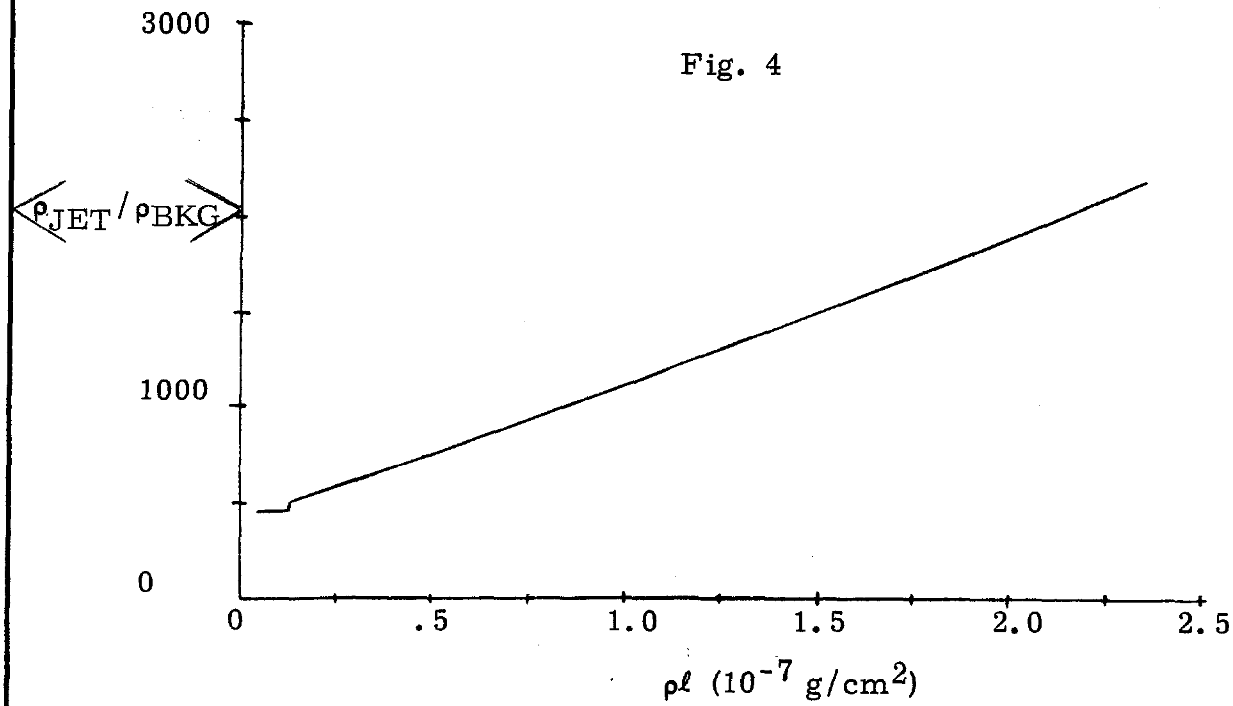

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Fig. 5